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EXECUTIVE SUMMARY

TRIP REPORT - ROBOTS 8 CONFERENCE & EXPOSITION

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The authors attended the Robots 8 International Conference and Exposition in Detroit, Michigan on June 4-7, 1984, to review the state-of-the-art in robotic hardware, programming and application, and to examine applicability of recent developments to Ontario Hydro requirements in areas such as remote welding, inspection, and maintenance. There were approximately eighty-five papers presen'ed on a wide variety of topics related to robotics, and approximately three hundred exhibitors representing the current state-of-the-art in robotic technology. Following is a commentary on highlights found significant in the conference and the concurrent trade show. The complete conference proceedings volumes were obtained and are available for review from the Welding Unit and from the Nondestructive & Fracture Evaluation Section, Metallurgical Research Department.

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INTRODUCTION

Over the past several years the sophistication and capabilities of robotic systems has rapidly increased, but this rate of increase appears to be levelling off. Many applications for robots do not require the robotic performance levels which can now be achieved and consequently the present emphasis in robotic development is in robotic peripherals, end-effectors, and systems directed towards the application of robots.

Advances in electric motor and servo-control technology are continuing and this is being used by robot manufacturers to increase design flexibility rather than performance levels. This is reflected in the wide diversity of size and joint configurations currently available in commercial robots. Sensors and vision systems are being used extensively in many robotic applications to increase the diversity and reliability of the various systems.

BASIC CONFIGURATIONS

Robot manipulators are generally designed as an arrangement of linear slides and/or rotary joints. The simplest arrangement has three linear slides at right angles. This allows XYZ Cartesian co-ordinate control and straight line motion without the necessity for complex trigonometric algorithms, and enables a high degree of accuracy and precision to be achieved. One such robot demonstrated its ability to quickly insert a 22.7 Kg (50 lb) 152.4 mm (6") diameter cylinder with only 0.0635 mm (2.5 thou) clearance without binding. In some systems a fully articulated arm was positioned in three dimensions by an overhead gantry to combine flexibility with a large working envelope.

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An increasing number of the smaller assembly type robots were horizontally articulated (all joints having vertical axes) and used linear slides to provide vertical motion. Vertical axis joints can be relaxed without being affected by gravity. Welding robots and tool handling robots as well as some of the larger assembly type robots tended to be vertically articulated with a base swivel. Load carrying capabilities of the robots ranged from a few grams to hundreds of kilograms.

MOTORS AND DRIVES

Many of the earlier robots were electro-hydraulically operated. However, as a result of the advances in electric servo-motor technology, the present trend is toward electrically powered robots. Electric drives are quieter, more efficient and do not leak hydraulic fluid. Due to various economic factors, the cost of electronic controls is dropping while the cost of mechanical drive elements such as gears is increasing. Consequently, the trend in electric drives is away from mechanically commutated DC motors toward DC brushless and variable frequency AC motors. In addition, motors are being designed to give higher torques at lower speed to reduce the need for gearing.

One recent development is a low inertia stepping motor which uses a magnetized disk instead of the usual cylindrical permanent magnet assembly for the rotor. In addition to its low inertia and high torque, it is capable of running at speeds of up to 1047 rad/sec(10,000 rpm,) giving it a high power density. It is said to fill the price/performance gap between stepping motors and electric servos.

Another motor design achieves very high torques at low speeds, thereby eliminating the need for gear reducers. It is a multiple pole, three phase, variable reluctance type motor which uses a resolver, of similar design, to electronically commutate the stator windings. A 152.4 mm (6") diameter motor of this design yields an output torque of up to 47.47 N.m (35 ft.lb).

Electronic motor controls are becoming more modular and general purpose. One such system, based on a microprocessor, is almost entirely digital, having its control strategies stored in read only memory. There are no potentiometer adjustments as all parameters are set via software. This enables it to control virtually any type of DC motor as long as it is mechanically commutated and uses a resolver for feedback. (A resolver is similar to an incremental shaft rotation encoder except that it has two sinusoidal analogue outputs separated by a ninety degree phase shift).

Backlash reduction and elimination are important for providing the accuracy and repeatability required from present-day robots. Two mechanical approaches are the harmonic drive and the orbital drive. The harmonic drive makes use of a flexible metallic gear which engages an internal gear having slightly more teeth. The flexing is driven by an elliptical ball bearing and the resulting rotation of the flexible gear is coupled to the output shaft. In the orbital drive, a rigid gear with sinusoidal teeth orbits within an internal gear with slightly more sinusoidal teeth. Cylindrical bearing rollers roll between the two gears which never touch, thereby reducing friction. As the smaller gear orbits within the larger gear it rotates at a slower speed and this rotation is coupled to the output shaft.

PERIPHERALS AND END-EFFECTORS

The ability of a robot to accomplish a given task depends to a large extent, in many cases, on the design of the end-effectors. Two types of systems for exchanging special purpose end-effectors were demonstrated. One of them was a conical turret with a number of end-effectors mounted on it. After the robot finished one task, the turret would rotate to the next end-effector and then begin the next task. The other type of system involved a clamping arrangement which allowed the robot to attach itself to a separately located end-effector. Electrical and pneumatic connections were made simultaneously with the mechanical connection. While many end-effectors were quite complex mechanically, there was widespread use of vacuum suction cups. These were used for very light and delicate loads as well as for heavy loads.

Three of the robots were equipped with a CO_2 laser for metal cutting and welding. These systems required a telescoping arrangement of prisms to transmit the beam from the laser. Generally, laser power levels were limited to approximately 5 KW and the penetration depth was 3.18 mm to 6.35 mm (1/8" to 1/4"). High pressure water jets at 344.7 MPa (50,000 psi) were also used as a robotic tool. These jets can cut rubber, wood, paper, Kevlar, and printed circuit board material at high speed. At lower pressures, water jets can be used for metal chip removal after machining. Other common robotic peripheral equipment included automatic holding jigs, parts indexers, rotary tables, conveyors and welding equipment.

WELDING DEVELOPMENTS

There are many welding systems being developed. Most, if not all, of these systems require parts to be brought to the robot. This is because most robotic welding is performed in manufacturing applications. But, in most manufacturing welding applications, uncertainties in dimensions of the part, geometry of the joint, and the welding process itself make the use of sensors essential to maintaining weld quality. Previous robotic arc welding systems relied

on pre-programmed torch motion and arc parameters, and yielded unsatisfactory welds in many cases. Appropriate sensors are required for tracking the required path or seam to be welded. A two pass seam tracking system is typically the easiest to implement. However, a single pass system is required for better control of the welding process. Of the single pass sensor systems that have been developed, all are at present only useful for very specific applications.

The development of single pass sensors that can be used during welding has been limited by several factors. Single pass sensors must be able to function near arc light and electrical interference, have little bulk and not interfere with the functional and mechanical operation of the torch, and must obtain sufficient and appropriate information to be able to perform a good weld. Three types of sensor systems have been developed:

1. A mechanically contacting sensor that rides along the joint in front of the weld pool can be used on some V-groove or similar joints. This type of sensor is good for measuring joint position only, but is highly tolerant of arc interference.

2. Thru-the-arc sensing can measure the voltage, current and power, while weaving, to control welding parameters and to follow a path. A variation of this system monitors the AVC* during GTA** welding while weaving across a seam.

3. A combined laser and camera vision system can measure the geometry, orientation and position of the joint and the weld puddle to facilitate the control of torch movement and welding process parameters. This type of system appears to have the most promise for single pass welding.

There were two welding systems of particular interest. One of them, a 300 amp GMA+ welding system available from Meta Machines (Fairey) and from Autoflex, incorporates a CCD camera and two lasers into a 57 mm(2.25inch) diameter torch. The integral system controller interfaces directly to a robot controller, and the torch sensors, and to appropriate monitoring and programming facilities. The result is a system that can track complex 3D seams in real time for lap, fillet and butt joints. The system is aimed primarily for use in GMA welding of thin sheet metal.

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*Automatic Voltage Control
**Gas Tungsten Arc Welding
+Gas Metal Arc Welding

Another system is still being developed at General Electric for GTA welding of complex aircraft engine components. A remote camera is connected to the welding torch with a coherent fiber optic bundle to view the puddle and joint axially along the torch electrode. Two parallel stripes of laser light are also projected onto the metal surface in front of the torch electrode for structured illumination. It is expected that when the system is completed, possibly by mid 1985, it will have the potential to control the weld path and welding process to perform a good weld on a part with a largely unknown joint position, orientation and geometry.

PARTS RECOGNITION

During the past few years there has been very rapid progress in the area of vision systems. These typically consist of a television camera interfaced to a computer, and a software package for extracting features from the image. In some cases, the camera is mounted on a robot, enabling a complex part to be inspected from different angles. One vision system was fast enough to inspect bolts "on the fly" as they came down a slide, and control a solenoid which determined whether the bolt ended up in the "accept" or "reject" bin. In addition to inspection, vision systems are enabling robots to cope with randomly oriented parts. In one such system one camera continuously scans a conveyor belt. When it detects a randomly located and randomly oriented gear, it informs a robot of the location and the robot picks it up. It then shows the gear to a second camera, rotating it until the vision system informs it that the gear has the correct orientation, and then inserts the gear into a gear box being manufactured. The same process is repeated with each succeeding gear which then meshes properly with the preceeding gear.

Another system for arranging randomly oriented parts uses an 80 x 80 matrix of tactile sensors instead of a camera. The robot uses an electro-magnet to remove a three-dimensional stamped part from a bin where they are randomly oriented. It then drops it onto the tactile sensor pad where three points of contact with the pad are sensed. The three points form a triangle which is compared by a computer with information about the part stored in memory. The computer is then able to determine the location and orientation of the part and give the robot instructions on how to pick up the part and put it into a jig so that it will be correctly located and oriented. Generally, in robotic manufacturing systems there is a strong emphasis on maintaining the correct orientation of parts throughout the process to keep down the cost.

SIMULATION & CONTROL

The application of CAD/CAM* systems to robotics has resulted in a number of robot simulation systems. Using stick diagrams or solid modelling of the robot arms, these systems provide a visual means of offline programming. Once a programming sequence has been written and debugged on the simulator,the resulting code can be sent directly to the actual robot. More emphasis is being put on contingency programming which allows a robot to continue productive activity even after some of its peripheral equipment has malfunctioned. In addition there is a growing dependency on software to prevent adjacent robots from colliding.

Numerous systems made use of personal computers such as the IBM PC**, Apple 2e, and the Radio Shack Model 100, in supervisory control type functions. One NC*** lathe was entirely controlled by an Apple 2e.

Networking of robots to a central control system is being commonly used in many applications where a number of robots are used in the process. Where electrically noisy environments make it difficult to send data rapidly over long distances, fibre optics can be used. One fibre optics system was capable of transmitting information serially at a rate of 50 Megabits/sec.

One area where progress has been slow is in the combination of remote manipulators with automatic robotic control. The reason for this appears to be a result of the heavy emphasis on manufacturing and mass production which characterizes the robotics industry.

ROBOT FAILSAFE SYSTEMS

When a robot system is installed at a location it is usually an "unknown" to the majority of workers in the vicinity, resulting in a general fear of the robot. One speaker cited a robot installation where janitors wouldn't clean the area around the robot. This situation, which partly results from mass media conditioning, is being acknowledged and robot users are attempting to better educate the workers in the robot environment. There are, however, dangers from robots that go out of control or perform unexpected motions. To improve safety, barriers, floor pads, light beams and proximity sensing systems have been developed and implemented. Also being developed is programmed software that maps the robot's safe working environment and uses appropriate sensors to modify the map as required. Systems such as these are necessary to protect the robot and items in its environment,but more importantly, the people who must

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*Computer Aided Design/Computer Aided Manufacturing
**International Business Machines Personal Computer
***Numerically controlled

work in the vicinity. The systems that have been developed either perform the safety checks using the robot controller or use a separate system to continuously monitor various sensors that depict the status of the robot's environment. In the past, robot safety has been considered separately, after the robot has been installed. The present trend is towards incorporating safety into the robot system before it is installed.

MOBILITY

Mobile robots are rapidly becoming a serious technology. These devices are usually battery powered and move along preprogrammed paths. In the manufacturing setting, they are primarily used for material handling, particularly for large heavy loads.

One unique device was developed for scrubbing barnacles off of the side of a ship. It uses magnets and suction cups to hang on to and move along the ship's hull, and has a rotating abrasive wheel. It also has the ability to operate according to a preprogrammed sequence.

Another device still under development is intended for inspection-type applications in hazardous environments. It is radio-controlled, uses a tractor-type drive and includes a television camera and a manipulator arm. A stick diagram simulation of the device showed it to be capable of climbing up a narrow staircase at a nuclear station.

CONCLUSION

Robotic technology has become very highly developed and undoubtedly it has great potential in many applications. The future growth of robotics will be influenced largely by the integration of appropriate sensors and vision systems, and also by the extent to which the capabilities of robotics are communicated to the people who are or may be using this technology. Outside of manufacturing, however, it should be noted that any application of robotics is likely to involve a sizeable development effort.

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